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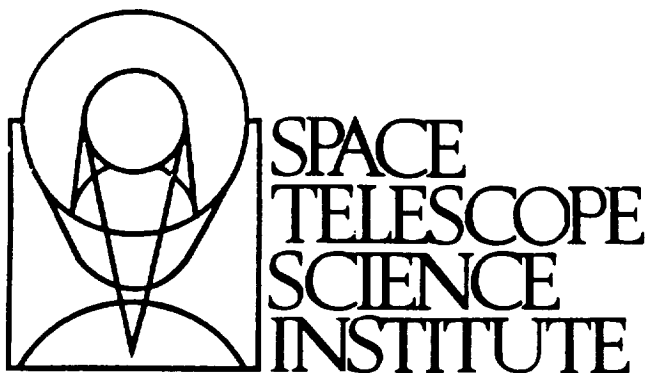
Final Technical Report
NAG5-2570

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NASA Grant No: NAG5-2570
Title: *A Distant, X-Ray Luminous Cluster of Galaxies at Redshift 0.83*
STScI Project No: J0951
Performance Pd: 04/15/94 - 06/14/97
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This paper describes the ASCA data analysis and the implications of the high temperature revealed for the cluster of galaxies MS1054-0321.



PREPRINT SERIES

No. 1247

A VERY HOT, HIGH REDSHIFT CLUSTER OF GALAXIES:
MORE TROUBLE FOR $\Omega_0 = 1$

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May 1998

A VERY HOT, HIGH REDSHIFT CLUSTER OF GALAXIES:
MORE TROUBLE FOR $\Omega_0 = 1$

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ABSTRACT

We have observed the most distant ($= 0.829$) cluster of galaxies in the *Einstein* Extended Medium Sensitivity Survey (EMSS), with the ASCA and ROSAT satellites. We find an X-ray temperature of $12.3^{+3.1}_{-2.2}$ keV for this cluster, and the ROSAT map reveals significant substructure. The high temperature of MS1054-0321 is consistent with both its approximate velocity dispersion, based on the redshifts of 12 cluster members we have obtained at the Keck and the Canada-France-Hawaii telescopes, and with its weak lensing signature. The X-ray temperature of this cluster implies a virial mass $\sim 7.4 \times 10^{14} h^{-1} M_{\odot}$, if the mean matter density in the universe equals the critical value ($\Omega_0 = 1$), or larger if $\Omega_0 < 1$. Finding such a hot, massive cluster in the EMSS is extremely improbable if clusters grew from Gaussian perturbations in an $\Omega_0 = 1$ universe. Combining the assumptions that $\Omega_0 = 1$ and that the initial perturbations were Gaussian with the observed X-ray temperature function at low redshift, we show that this probability of this cluster occurring in the volume sampled by the EMSS is less than a few times 10^{-5} . Nor is MS1054-0321 the only hot cluster at high redshift; the only two other $z > 0.5$ EMSS clusters already observed with ASCA also have temperatures exceeding 8 keV. Assuming again that the initial perturbations were Gaussian and $\Omega_0 = 1$, we find that each one is improbable at the $< 10^{-2}$ level. These observations, along with the fact that these luminosities and temperatures of the high- z clusters all agree with the low- z $L_X - T_X$ relation, argue strongly that $\Omega_0 < 1$. Otherwise, the initial perturbations must be non-Gaussian, if these clusters' temperatures do indeed reflect their gravitational potentials.

1. INTRODUCTION

Clusters of galaxies occupy a special position among celestial self-gravitating structures, as they are the largest virialized objects in the universe. If all the cosmic structures we currently see grew hierarchically from small seed perturbations in the early universe, as many lines of evidence now suggest (e.g., Peebles 1993), then the largest clusters of galaxies are also the most recent virialized structures to have appeared on the cosmological scene. The most massive of all clusters, which represent the most extreme high-density peaks on scales $\sim 10^{15} M_{\odot}$ in the initial field of density perturbations, correspond to several- σ events if the perturbations are Gaussian.

Because massive clusters represent the high- σ tail of the distribution, their number density should rise dramatically as the overall amplitude of the perturbations grows. This characteristic of cluster formation renders massive cluster evolution particularly sensitive to the mean matter density of the universe, currently equal to Ω_0 , in units of the critical density $3H_0^2/8\pi G$. If $\Omega_0 \approx 1$, perturbations should still grow like $(1+z)^{-1}$, and evolution in the number density of distant clusters with redshift should be rapid. If $\Omega_0 \ll 1$, perturbation growth has virtually stopped, and massive cluster evolution should be much more mild.

Evolution in the distribution of cluster masses sensitively indicates Ω_0 , but measuring the virial masses of clusters (M_{vir}) is difficult, even at

low redshifts. A much more straightforward observational task is to measure how the X-ray temperatures (T_X) of clusters depend on redshift and then to use a model to relate T_X to M_{vir} (e.g., Oukbir & Blanchard 1992). The *Advanced Satellite for Cosmology and Astrophysics* (ASCA) (Tanaka, Inoue, & Holt 1994) now makes such tests possible because it can measure the temperatures of the most luminous X-ray clusters at high redshifts (Yamashita 1994; Furuzawa et al. 1994; Donahue 1996). Henry (1997) has recently published a temperature function for 10 massive clusters at $z \sim 0.3$, chosen from the *Einstein* Extended Medium Sensitivity Survey (EMSS) (Gioia et al. 1990; Henry et al. 1992). His comparison of the $z \approx 0.3$ – 0.4 temperature function with the $z \approx 0$ temperature function suggests that $\Omega_0 \approx 0.5$ and rules out $\Omega_0 = 1$ with 99% confidence.

In this paper we attempt to extract the maximum leverage out of this test for Ω_0 by measuring the temperature of the highest-redshift cluster in the EMSS, MS1054-0321 at $z = 0.83$. We present both an ASCA spectrum and a ROSAT HRI image of this very luminous cluster ($L_x = 5.6 \times 10^{44} h^{-2} \text{ erg s}^{-1}$ 2–10 keV rest frame, $L_x = 1.1 \times 10^{45} h^{-2} \text{ erg s}^{-1}$ bolometric). For $q_0 = 0.1$, $L_x = 7.7 \times 10^{44} h^{-2} \text{ erg s}^{-1}$ 2–10 keV rest frame. Luppino & Kaiser (1997) provide a true color optical image and a weak lensing map. After presenting the observations in § 2, we examine how they constrain Ω_0 in § 3, finding that they

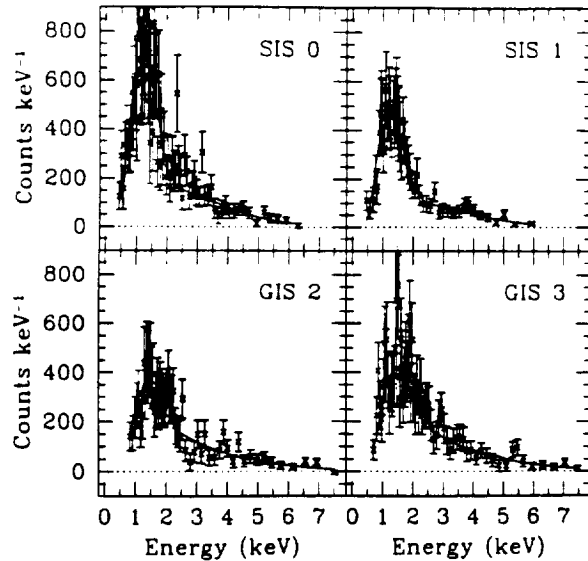


Figure 1—We plot the X-ray spectra from each of the four ASCA telescopes for the cluster MS1054-0321. Each spectrum has over 1000 X-ray counts. (See Table 1.) The best-fit model is drawn with a solid line. The spectra we display were binned such that each energy bin contained a minimum of 16 (SIS) or 25 (GIS) counts.

intrinsic absorption component, to a 90% upper limit of $N_H < 1.4 \times 10^{21} \text{ cm}^{-2}$. Thus, we fixed soft X-ray absorption at an HI value of $3.7 \times 10^{20} \text{ cm}^{-2}$ (Gioia et al. 1990). Each SIS spectrum was fit with its own normalization; the normalizations of the GIS spectra were constrained to be the same. The parameters varied to provide a fit to 4 spectra were therefore the 3 independent normalizations (1 for each SIS spectrum, 1 for both GIS spectra), a single emission-weighted temperature, and the metallicity (iron abundance). Examples of the binned spectra and best-fit model convolved with each telescope's response matrix are found in Figure 1. The best-fit redshifted temperature to the binned-by-four spectrum was $12.4 \pm 3.6 \text{ keV}$ with an upper limit on iron abundance of 0.22 solar, keeping the absorption fixed. If we used the SIS spectra regrouped to a minimum of 16 counts per bin, the best-fit temperature was virtually the same: $12.3 \pm 3.1 \text{ keV}$ with an upper limit on the iron abundance of < 0.25 solar. All uncertainties quoted are the 90% confidence levels for a 1-dimensional fit ($\Delta\chi^2 = 2.70$), and all fits have an acceptable reduced χ^2 of $\sim 0.8 - 0.9$. Figure 2 shows the two-parameter χ^2 contours for the cluster metallicity and T_X in keV.

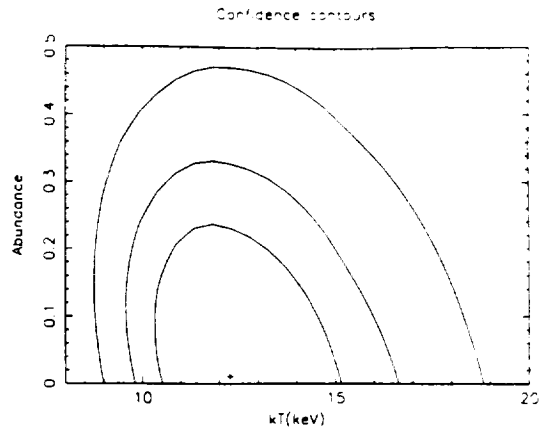


Figure 2—We plot the two-dimensional χ^2 contours at 68.3%, 90% and 99% confidence levels ($\Delta\chi^2 = 2.30, 4.61$ and 9.21) for the cluster iron abundance in units of the solar abundance and temperature in keV. These contours represent the confidence contours of simultaneous fits to the SIS spectra and to GIS spectra binned such that each bin contained a minimum of 16 and 25 counts respectively.

2.2. Optical Corroboration

The available optical data on this cluster corroborate the high temperature measured by ASCA. Weak lensing observations of MS1054-0321 by Lupino & Kaiser (1997) show that its mass within $0.5 h^{-1} \text{ Mpc}$ is $(5 - 11) \times 10^{14} h^{-1} \text{ Mpc}$, depending on the redshift distribution of the lensed galaxies. In an isothermal potential, its mass distribution corresponds to an isotropic one-dimensional velocity dispersion $\sim 1100 - 2200 \text{ km s}^{-1}$, consistent with the value expected from the ASCA temperature: $(kT_X / \mu m_p)^{1/2} = 1400 \pm 170 \text{ km s}^{-1}$ (90% confidence limits).

In addition, we have obtained the redshifts of twelve cluster members with the CFHT Multi-Object Spectrograph (MOS) on April 13, 1994 and with the LRIS (Oke et al. 1995) at Keck on January 4, 1995. These are listed in Table 2. Using Timothy Beers' program ROSTAT, we calculated their mean redshift and velocity dispersion, finding $z = 0.829 \pm 0.008$ and a velocity dispersion of $1360 \pm 450 \text{ km s}^{-1}$ (90% confidence interval). (The observed redshift dispersion has been corrected to first order for cosmological redshift by dividing by $1 + z$). Several alternative methods (Beers, Flynn, & Gebhardt 1990) give the same answer within the uncertainties. While the small numbers of redshifts do not constrain the velocity dispersion very well, the value we find is consistent with both the lensing results and the X-ray temperature.

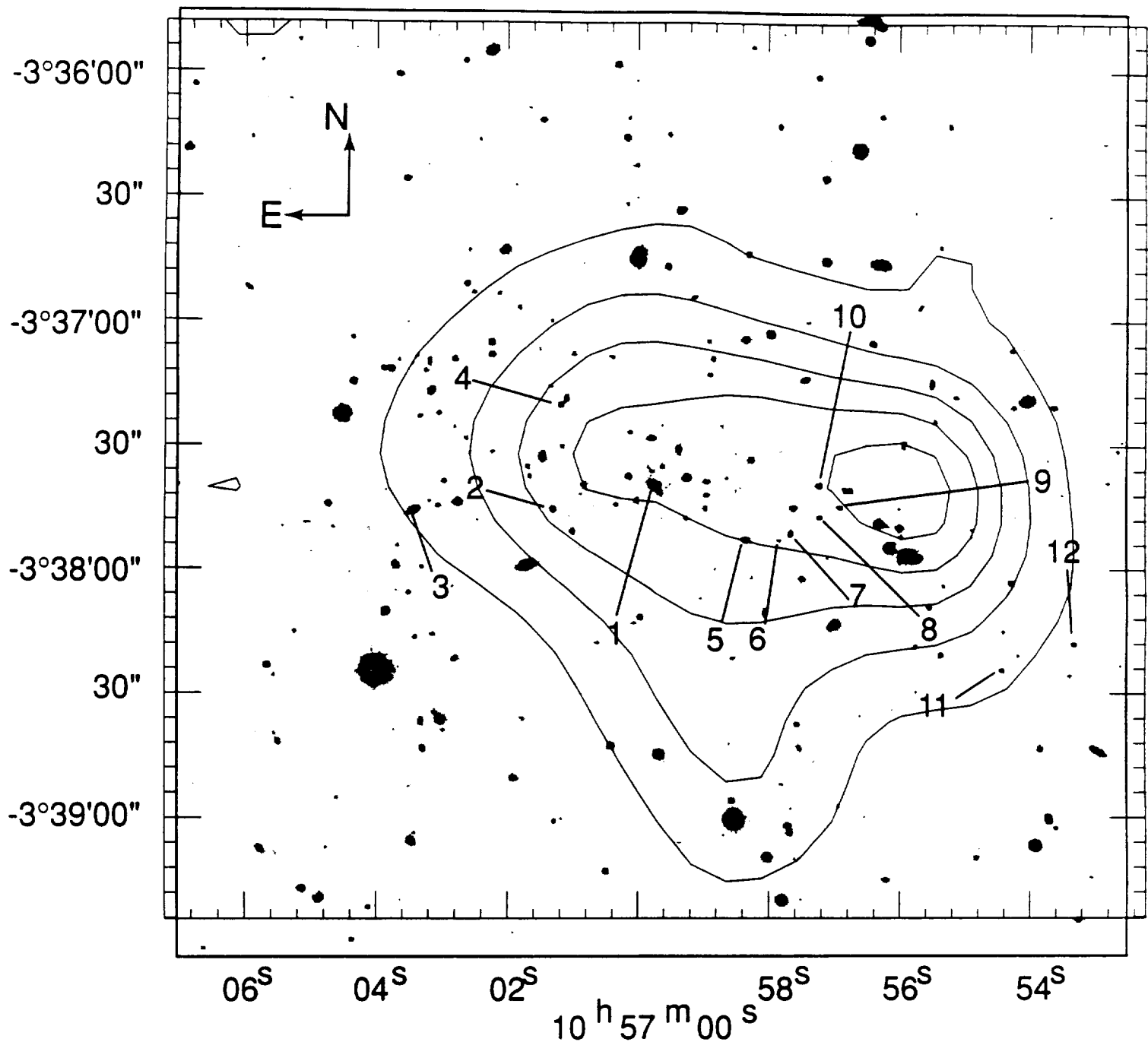


Plate 1—The central $3.75' \times 3.75'$ of the cluster MS1054-0321. The optical image is a 14,400 second I-band image taken with the University of Hawaii 88-inch (Gioia & Luppino 1994). The ROSAT HRI image, a sum of all available HRI data for a total livetime of 121,590 seconds, was rebinned into $8'' \times 8''$ pixels and adaptively smoothed with three Gaussians with sigmas of 16, 14.3, and 12.6 arcseconds corresponding to counts in a pixel of < 10 , 10–13.5 and > 13.5 . The sigmas were chosen so that the products of the number of counts and σ^2 were roughly constant. The background was 9.4164 counts per pixel. The net contour levels are 1, 2.8, 4.6, 6.4, 8.2, and 10 counts per pixel. These net count rates correspond to X-ray surface brightnesses of 1.4, 3.9, 11.6, and $14.0 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ arcmin}^{-2}$ assuming that 1 HRI count $\sim 2.8 \times 10^{-11} \text{ erg cm}^{-2}$. The galaxies are marked with identifications corresponding to Table 2. The central galaxy is at RA(2000)=10 56 59.9 and Dec(2000) = $-03\ 37\ 37.3$, as measured from our HST image of this cluster (Donahue et al., in preparation).

The asymmetric appearance of the cluster in these high resolution images warns us that the relationship between its mass and its temperature might not be as simple as a spherical, hydrostatic, isothermal model would predict. However, recent hydrodynamic simulations of cluster formation beginning with cosmological initial conditions indicate that the systematic errors on cluster masses derived using a scaling relation between mass and temperature are relatively small, typically $< 20\%$ even when some substructure is present (Evrard, Metzler, & Navarro 1996). Higher resolution simulations of individual cluster mergers, whose initial conditions are not dictated by hierarchical structure formation, indicate that errors in the estimated mass can be somewhat larger ($\lesssim 50\%$) after a recent merger, but these errors tend to yield *underestimates* of the cluster's mass (Roettiger, Burns & Loken 1996; Schindler 1996). The following discussion will therefore focus on the implications of the cluster temperature alone, assuming that the emission-weighted temperature is representative of the virial temperature. Mass errors at the 20% level do not affect the qualitative results of the ensuing discussion.

3. CONSTRAINTS ON TEMPERATURE EVOLUTION

This cluster, MS1054-0321, is one of the hottest clusters known. If $\Omega_0 = 1$, structure formation simulations show that we can estimate its virial mass by assuming that the mean density within its virialized region is ~ 200 times the critical density at the cluster's redshift and that the cluster itself is isothermal (Evrard et al. 1996; Eke et al. 1996). The virial mass of MS1054-0321 would then be approximately $M_{\text{vir}} \sim [2kT_X/\mu m_p (1+z)]^{3/2} (10H_0G)^{-1} \sim 7.4 \times 10^{14} h^{-1} M_\odot$ within $r_{200} = 1.5h^{-1}$ Mpc. (We note that this relation is equivalent to assuming $\beta = 1$ in a standard X-ray mass relation for an isothermal gas.) Such a massive cluster at such a high redshift severely challenges models of hierarchical structure formation with $\Omega_0 = 1$ (Evrard 1989; Peebles, Daly, & Juszkievicz 1989; Donahue 1993). This section elucidates how severe those challenges are.

Because the virial masses of clusters are much harder to measure than their temperatures, we will restrict this analysis to focus on temperature evolution, relying on T_X to be a surrogate for M_{vir} . The analysis will therefore depend on the temperature-mass relation we assume. In an $\Omega_0 = 1$ universe, this relation is relatively simple: $T_X \propto M_{\text{vir}}^{2/3} (1+z)$. If $\Omega_0 \ll 1$, this relationship breaks down below $z \sim \Omega_0^{-1} - 1$ as the development of structure stagnates.

3.1. Rarity of Hot Clusters at High- z

In order to determine the rarity of a cluster as hot as MS1054-0321 in an $\Omega_0 = 1$ universe seeded with Gaussian perturbations, we will assume that the Press-Schechter formula (Press & Schechter 1974) adequately describes the mass function of virialized objects, an assumption borne out by numerical simulations (e.g., Lacey & Cole 1994, Eke et al. 1996). In integral form, the comoving mass density of virialized objects with virial masses greater than M is then

$$\rho(> M) = \rho_0 \text{erfc}(\nu_c/\sqrt{2}) = \frac{2\rho_0}{\sqrt{\pi}} \int_{\nu_c/\sqrt{2}}^{\infty} e^{-x^2} dx, \quad (1)$$

where ρ_0 is the current mean matter density and ν_c is the critical threshold at which perturbations virialize. This threshold is $\nu_c = \delta_c(t)/\sigma(M)D(t)$, where $\sigma(M)$ describes the rms amplitude of linear perturbations on mass scale M , $D(t)$ describes their linear growth rate, and $\delta_c(t)$ is the linear overdensity at which perturbations virialize. If $\Omega_0 = 1$, then $\nu_c \propto (1+z)$ at a fixed mass scale M .

This integral form of the Press-Schechter formula makes its theoretical underpinnings somewhat more apparent than the more familiar differential form does. The formalism assumes that the original linear density perturbations from which structure grew, smoothed over a length scale corresponding to mass M , follow a gaussian distribution with a dispersion proportional to $\sigma(M)$. As the perturbations grow, the most prominent of them collapse and virialize when their amplitudes exceed some threshold. The parameter ν_c expresses how many standard deviations away from the mean amplitude a positive density perturbation must lie to have collapsed and virialized by time t . The total mass density in virialized perturbations of mass M or greater is then proportional to the integral over the tail of this Gaussian distribution from ν_c to infinity, which yields the complementary error function in the above expression if $\sigma(M) \rightarrow 0$ as $M \rightarrow \infty$. Because the typical amplitudes of perturbations decline with increasing M , the number density of virialized objects exceeding mass M is approximately $M^{-1}\rho(> M)$. At several standard deviations away from the mean, virialized objects with masses significantly exceeding M are much rarer than objects of mass M , so this approximation for the mean number density of virialized clusters is good to a few tens of percent.

We will now proceed to determine the expected number density of clusters like MS1054-0321 at high redshift as follows:

virialized mass density in such clusters is similar to the case of MS1054-0321, implying $\nu_c > 3.4$ at $z = 0$ and $\nu_c > 5.2$ at $z = 0.54$. For $\Omega_0 = 1$ and Gaussian perturbations, the expected number density of > 8 keV clusters at $z = 0.54$ is then $< 8.6 \times 10^{-11} h^3 \text{Mpc}^{-3}$. Each of the two hot EMSS clusters at $z = 0.54$ would therefore be rarer than one in a hundred, with a joint improbability of order a few times 10^{-4} , somewhat more probable than the chance occurrence of MS1054-0321.

In summary, given the three hot high redshift clusters in the EMSS, the implied number density of clusters with $T_X > 8$ keV at $z = 0.5 - 0.9$ is $\sim 1.6 \times 10^{-8} h^3 \text{Mpc}^{-3}$. The probability of all three clusters appearing in the volume sampled by the EMSS in an $\Omega = 1$ Universe is $\sim 10^{-6}$ if the initial density perturbations have a Gaussian distribution.

Universes with $\Omega_0 \approx 0.3$ have no problem accomodating such hot clusters at these redshifts. Eke et al. (1996; see also Viana & Liddle 1996) show that the cluster temperature function evolves very little in an $\Omega_0 = 0.3$ universe with no cosmological constant and only modestly in a flat universe with the same Ω_0 . The number density of > 8 keV clusters from Henry (1997) is $\sim 5 \times 10^{-8} h^3 \text{Mpc}^{-3}$, quite close to the value we find at $z \sim 0.5$. The statistics of hot clusters at $z > 0.5$ therefore add substantial weight to the growing body of evidence emerging from cluster evolution that $\Omega_0 \approx 0.3 - 0.5$ (e.g., Carlberg et al. 1997; Henry 1997; Bahcall, Fan, & Cen 1997).

3.3. High- z L_X - T_X Relation

Cluster evolution from $z \sim 0.5$ to the present should be modest at best in a universe with low Ω_0 . Here we show that the relationship between the X-ray luminosity (L_X) and the X-ray temperature of MS1054-0321 is similar to the relationship derived from lower-redshift clusters. Edge & Stewart (1991b) found that $L_X \approx (8.8 \times 10^{41} h^{-2} \text{erg s}^{-1}) (T_X/1 \text{ keV})^{2.79 \pm 0.05}$ in the 2 - 10 keV band for low-redshift clusters, while Mushotzky & Scharf (1997) demonstrate that clusters observed at $z > 0.14$ by ASCA, including MS0451-03 (Donahue 1996) and MS0016+16 (Yamashita 1994; Furuzawa et al. 1994), do not deviate appreciably from this relation. Our observations indicate that $L_X(2 - 10 \text{ keV}) \approx 7.7 \times 10^{44} h^{-2} \text{erg s}^{-1}$ for MS1054-0321 in its own rest frame ($q_0 = 0.1$), implying an expected temperature of 11.3 keV, on the lower edge of our one-dimensional 90% confidence interval.

The lack of evidence for L_X - T_X evolution in our observation of MS1054-0321 is consistent with the other evidence for $\Omega_0 < 1$, but this test for Ω_0 is not as powerful as the temperature function

test, as discussed in Section 3.2. Some cluster evolution models predict little evolution in the L_X - T_X relationship in an $\Omega_0 = 1$ universe, as long as the minimum entropy of the X-ray gas remains the same for all clusters regardless of redshift (Kaiser 1991, Evrard & Henry 1991, Bower 1997). The lack of evolution in L_X - T_X would then require some sort of non-gravitational heating of the X-ray gas.

4. SUMMARY

The ASCA observations we have presented here imply that the EMSS cluster MS1054-0321 at $z = 0.83$ has an X-ray temperature of $12.3^{+3.1}_{-2.1}$ keV. Supporting optical redshifts of 12 member galaxies (this paper) and the weak lensing map (Luppino & Kaiser 1997) provide a velocity dispersion and a lensing mass that agree with the mass inferred from the high X-ray temperature. Our ROSAT image exhibits significant substructure, but numerical modelling of cluster evolution has shown that the presence of substructure does not preclude using a cluster's X-ray temperature to estimate its virial mass (e.g., Evrard et al. 1996).

This high a temperature in so distant a cluster is powerful evidence that $\Omega_0 < 1$. Using the integral Press-Schechter relation and the current temperature function of clusters, we calculate the expected number density of such hot clusters at $z = 0.83$, under the assumptions of Gaussian perturbations and $\Omega_0 = 1$. We find that the product of the expected number density and the effective volume of the EMSS in the $z = 0.5 - 0.9$ redshift bin is less than a few times 10^{-5} . Similar calculations for two other hot EMSS clusters at $z \approx 0.54$ give probabilities less than a few times 10^{-3} for each one.

For $\Omega_0 \approx 0.3$, the temperature function of hot clusters is expected to evolve very little to redshifts > 0.5 (Eke et al. 1996), so that the hot EMSS clusters are quite consistent with a low- Ω_0 universe. We also find that MS1054-0321 luminosity and temperature are consistent with the low- z L_X - T_X relation, a result also consistent with $\Omega_0 < 1$. These results strongly support the mounting body of evidence (e.g., Carlberg et al. 1997) showing that the mean density of matter in the universe is $\Omega_0 \approx 0.3$.

Acknowledgements

MD acknowledges Timothy Beers for the use of his ROSTAT program to calculate velocity dispersions, and helpful discussions with Carlos Frenk and Bharat Ratra at the Aspen Center for Physics. This work was supported by NASA ROSAT

TABLE 1. ASCA OBSERVING INFORMATION

Detector	Aperture Radius Arcmin	Count Rates s^{-1}	Useful Exposure Time s
SIS0	2.53	0.019	62,019
SIS1	3.25	0.013	58,176
GIS2	5.00	0.012	65,534
GIS3	5.00	0.016	65,920

TABLE 2. MEMBER GALAXY REDSHIFTS

ID	Redshift	Offset E/W (+/- ")	Offset N/S (+/- ")
1 (cD)	0.8309 ± 0.0008	0.0	0.0
2	0.8342 ± 0.003	+23	-6
3	0.8127 ± 0.0003	+56	-5.5
4	0.8213 ± 0.0007	+37	+30
5	0.830 ± 0.008	-14	-20
6	0.8209 ± 0.001	-29	-13
7	0.8286 ± 0.001	-31.5	-11.5
8	0.8353 ± 0.0006	-38	-8
9	0.8332 ± 0.001	-43	-6
10	0.8143 ± 0.002	-38	+0.5
11	0.8378 ± 0.003	-80	-44
12	0.8319 ± 0.002	-97.5	-38.5

Final Patent/Invention Report

Grant #: NAG5-2570

Title: A Distant X-Ray Lumious cluster of Galaxies at Redshift 0.83

Principal Investigator: Dr. Megan Donahue

No patents or inventions resulted from this grant.

FEDERAL CASH TRANSACTION REPORT

(See instructions on the back. If report is for more than one grant or assistance agreement, attached completed Standard Form 272-A.)

Approved by OI

Management and Budget, No. 80-R0182

1. Federal sponsoring agency and organizational element of which this report is submitted.

NASA Goddard Space Flight Center
Accounting Branch Code 151-2
Greenbelt, MD 20771

2. RECIPIENT ORGANIZATION
Name

SPACE TELESCOPE SCIENCE INSTITUTE

Number and Street

3700 SAN MARTIN DRIVE

City, State & Zip Code:

BALTIMORE, MD 21218

4. Federal grant or other identification number.

NAG5-2570

5. Recipient's account number identification number

G001-95100

6. Letter of credit number

80005122

7. Last payment voucher number

N/A

Give total number for this period

8. Payment Vouchers credited to your

Account

\$18,399.64

9. Treasury checks received

\$0.00

10. PERIOD COVERED BY THIS REPORT

FROM: 04/15/94

TO: 06/14/97

3. FEDERAL EMPLOYER

86-0138043

IDENTIFICATION NO.

11. STATUS OF
FEDERAL
CASH

(See specific
instructions
on the back)

a. Cash on hand beginning of reporting period.

0.00

b. Letter of credit withdrawals - wire transfer

18,399.64

c. Treasury check payments

0.00

d. Total receipts (sum of lines b and c)

18,399.64

e. Total cash available (Sum of lines a and d)

18,399.64

f. Gross disbursements

18,399.64

g. Federal share of program income

0.00

h. Net disbursements (Line f minus line g)

18,399.64

i. Adjustments of prior periods

0.00

j. Cash on hand end of period

0.00

12. THE AMOUNT SHOW

ON LINE 11J, ABOVE,
REPRESENTS CASH RE-

QUIREMENTS FOR THE
ENSUING

Days

13. OTHER INFORMATION

a. Interest income

0.00

b. Advances to subgrantees or subcontractors

0.00

14. REMARKS (Attach additional sheets of plain paper, if more space is required)

FINAL 272 REPORT NAG5-2570

15.

Certification

I certify to the best of my
knowledge and belief that
this report is true in all respects
and that all disbursements have
been made for the purpose and
conditions of the grant or agreement

AUTHORIZED
CERTIFYING
OFFICIAL

SIGNATURE

Marianne W. Johnson

TYPED OR PRINTED NAME AND TITLE

MARIANNE W. JOHNSON/ACCOUNTING SPECIALIST

TELEPHONE

(410) 338-4812

DATE REPORT SUBMITTED

7/24/97

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FROM (month, day, year) TO (month, day, year)

04/15/94 06/14/97

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FEDERAL GRANT OR OTHER IDENTIFICATION NUMBER (Show a subdivision by other identifying numbers if required by the Federal Sponsoring Agency)	RECIPIENT ACCOUNT NUMBER OR OTHER IDENTIFYING NUMBER	FEDERAL SHARE OF NET DISBURSEMENTS	
		NET DISBURSEMENTS (Gross disbursements less program income received) FOR REPORTING PERIOD	CUMULATIVE NET DISBURSEMENTS
(a)	(b)	(c)	(d)
NAG5-2570	G001-95100	0.00	18,399.64
5. TOTALS (Should correspond with amounts shown on SF 272 as follows: column (c) the same as line 11h; column (d) the sum of lines 11h and 11i of this SF 272 and cumulative disbursements shown on last report. Attach explanation of any differences.)		0.00	18,399.64

EQUIPMENT AND PROPERTY INVENTORY REPORT

Principal Investigator: Dr. Megan Donahue

Grant: NAG5-2570

Equipment/Property Purchased:

<u>Tag Number</u>	<u>Item Description</u>	<u>Model Number</u>	<u>Location</u>	<u>Cost</u>
GR000555	SPARCStation 20	600-3355-02	327	\$ 2,726*
GR000556	17" Color Monitor	GDM-17E10	327	\$ 1,010*
GR000585	Keyboard, Country kit	Type 5	327	\$ 117*
GR000756	Tape drive 4-8GB 4 MM Unipack	611	128	\$ 1,214
GR000764	Keyboard, Country kit	Type 5C	128	\$ 150
GR000765	SPARCStation 4	544	128	\$ 2,531
GR000766	17" Color Monitor	GDM-17E20	128	\$ 1,196
GR000636	Single disk drive	ST41080N	S209A	\$ 2,000
				<u>\$10,944</u>

*The cost of these was split 39%/61% between this grant and NAG5-2615